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(54) Abstract Title

Polycrystalline diamond cutters having modified residual stresses

(57) The residual stresses that are experienced in a polycrystalline diamond cutter (PDC) 10, which lead to cutter failure, can be effectively modified by selectively thinning a carbide substrate 14, which comprises additional binder constituents such as cobalt, nickel, iron, or an alloy of these. Prior to the selective thinning, the cutter 10 is subjected to high temperature, high pressure (sinter) processing, to selective varying of the material constituents of the substrate, to an annealing process during sintering, or to a post-process stress relief anneal, in order to achieve a desired state of compression in the diamond table and a desired residual stress in the substrate.

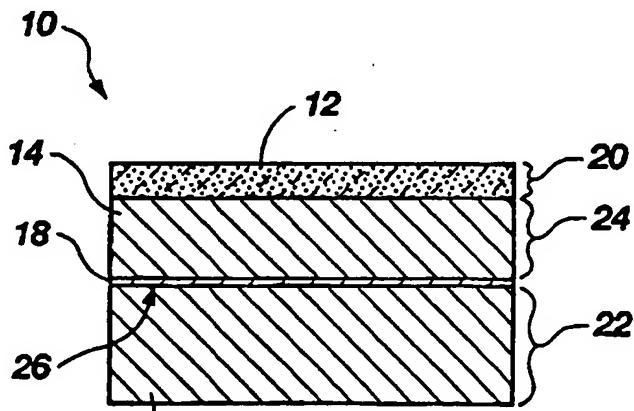
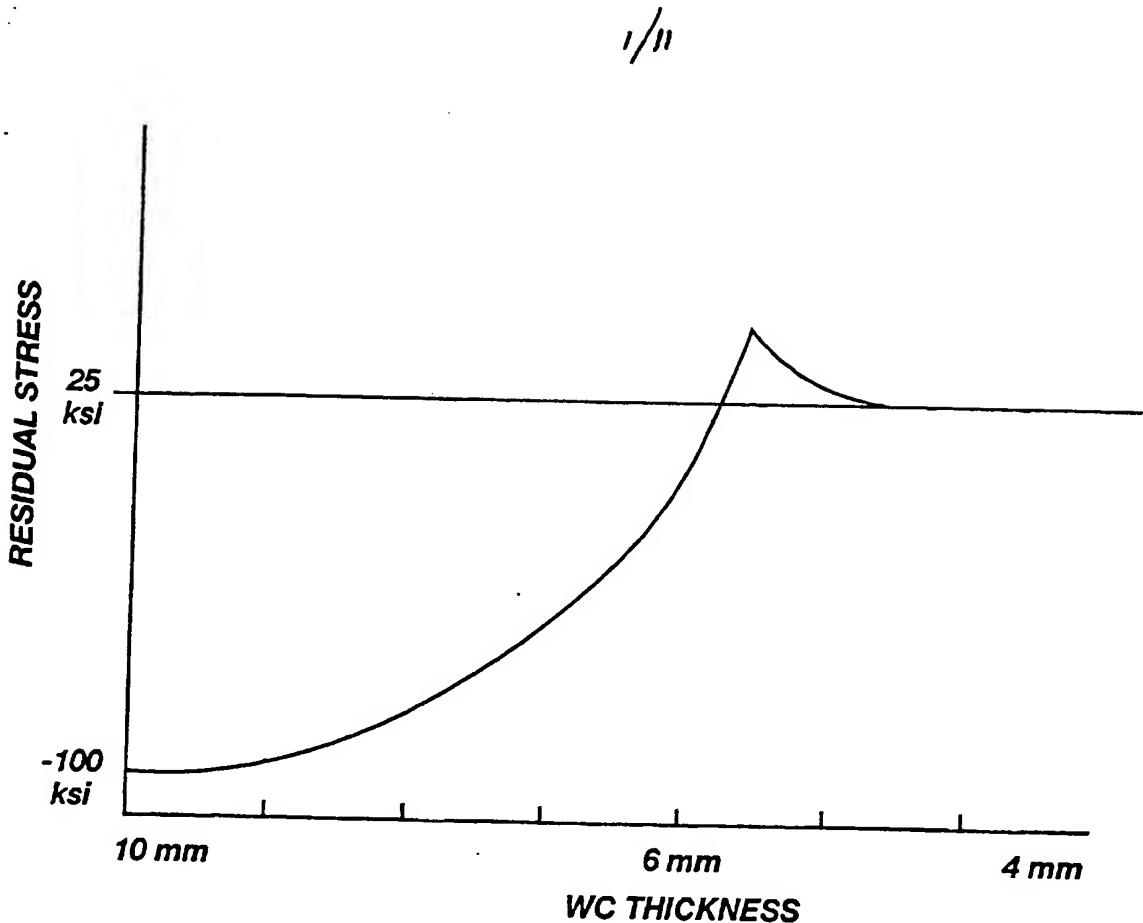
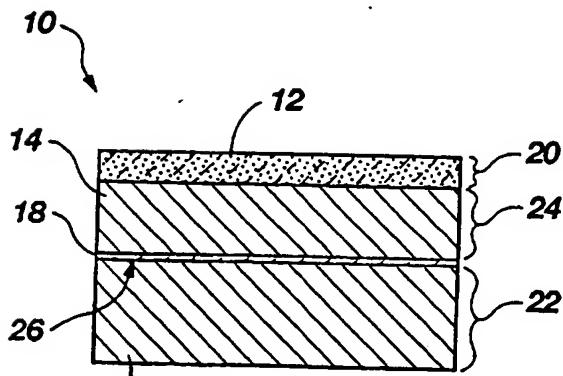


Fig. 2

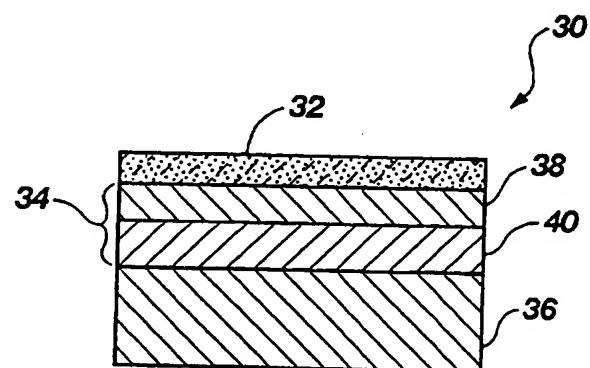
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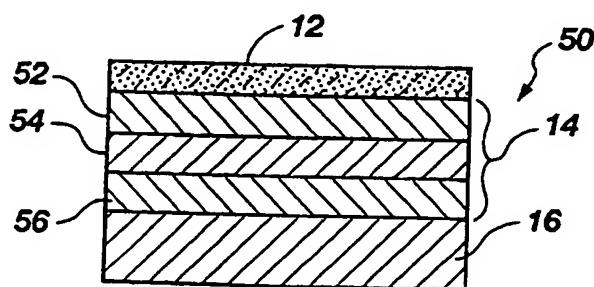
**Fig. 1**



**Fig. 2**



**Fig. 5**



**Fig. 6**

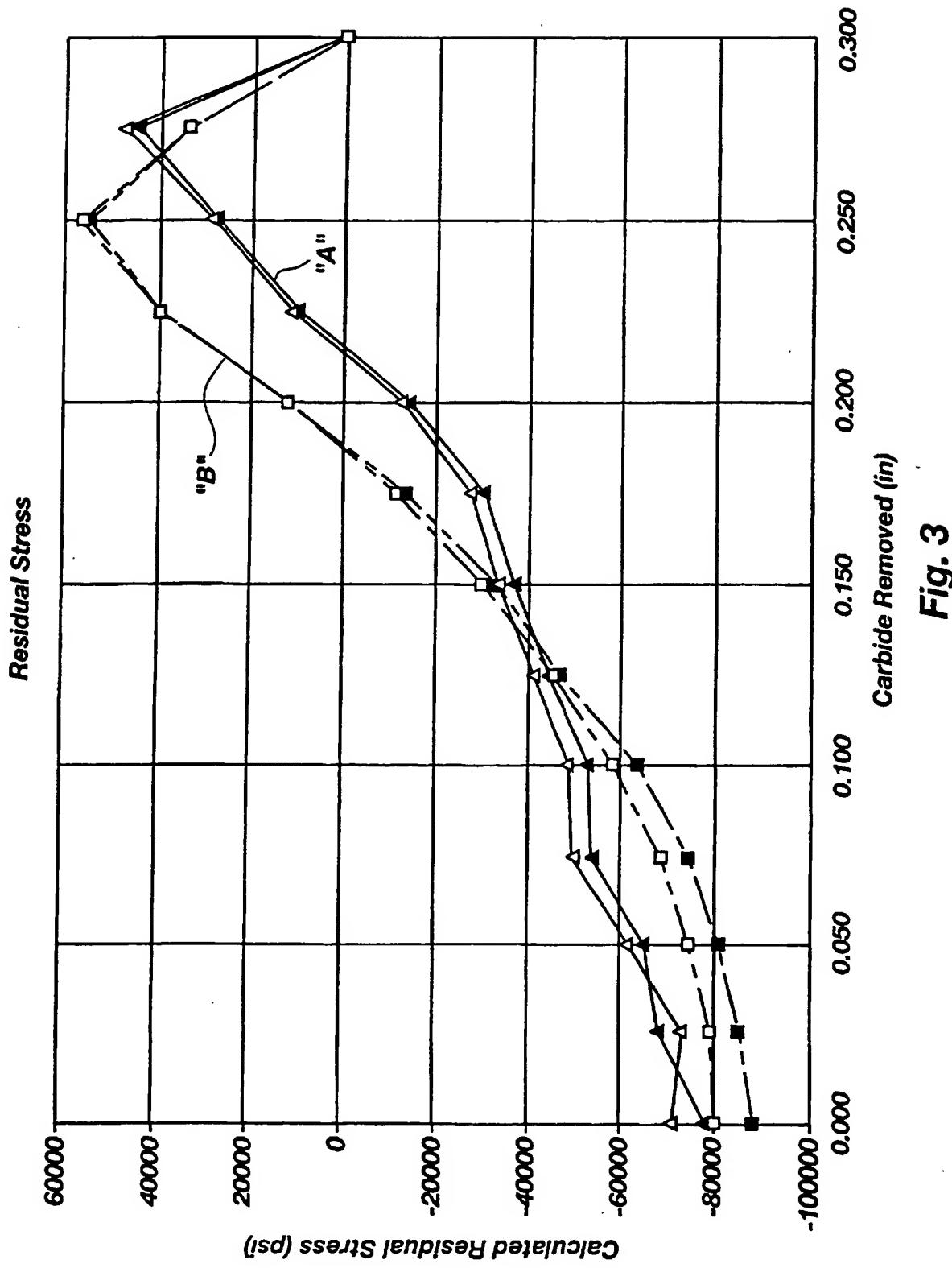


Fig. 3

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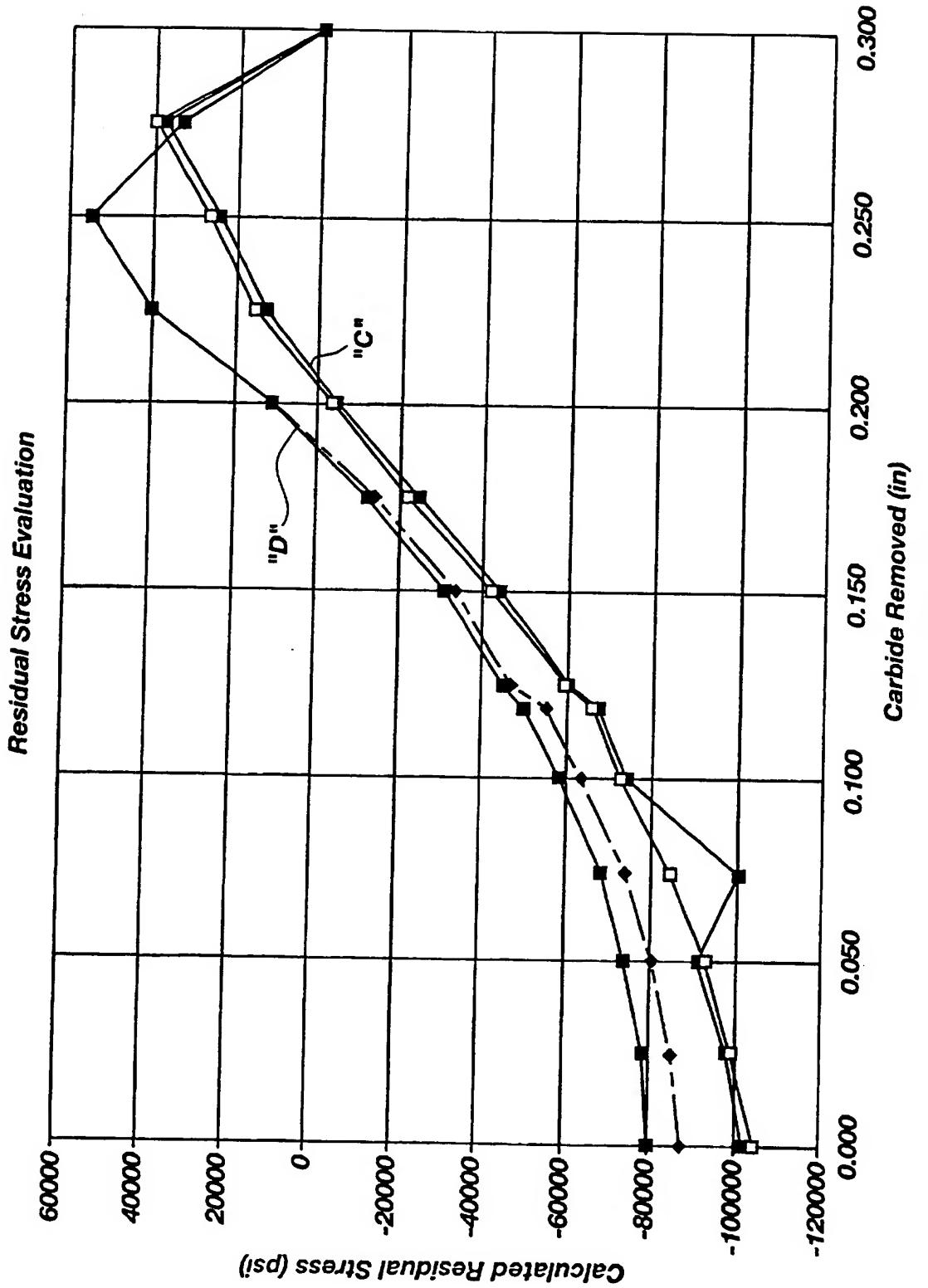


Fig. 4

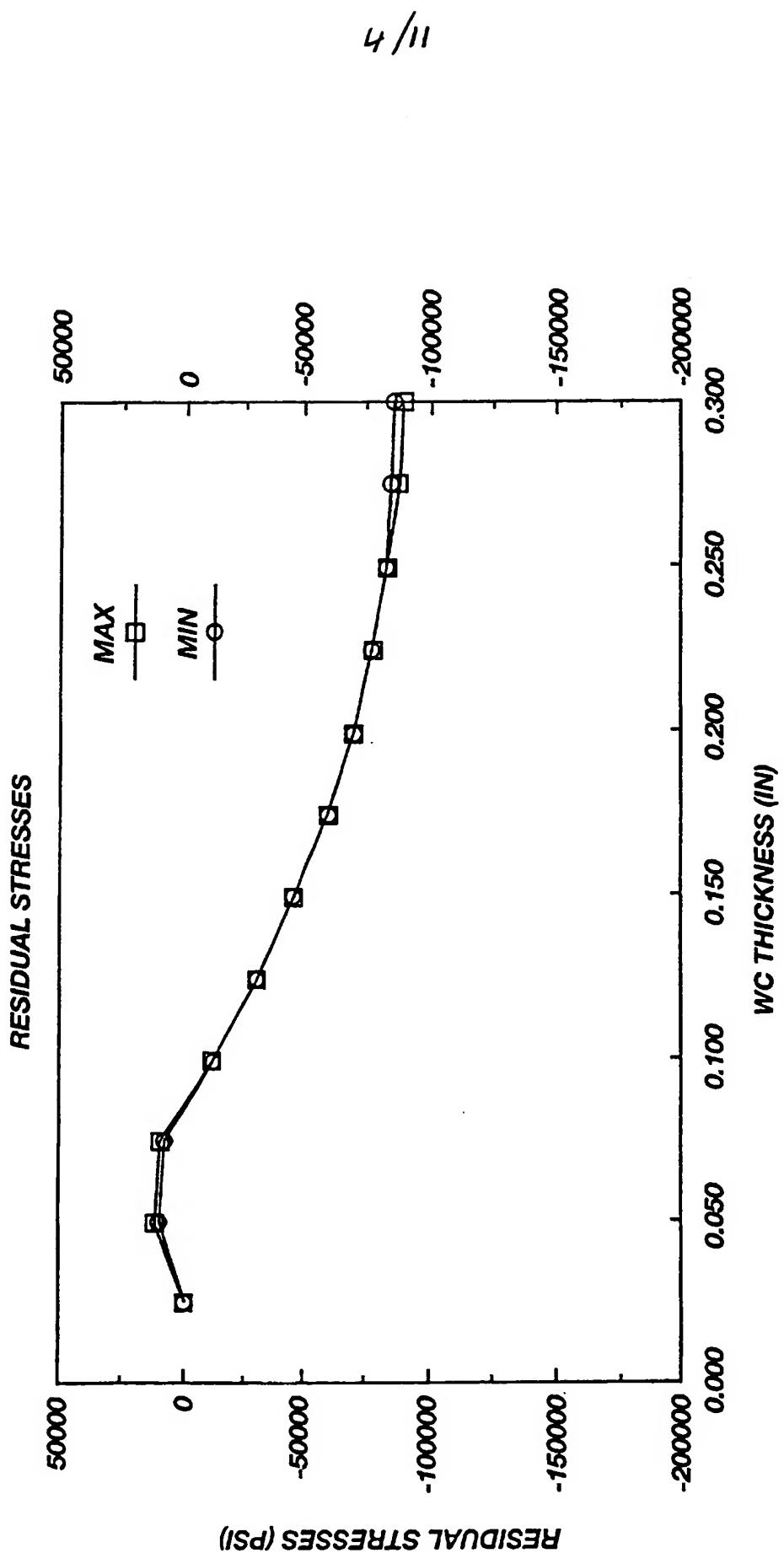


Fig. 7

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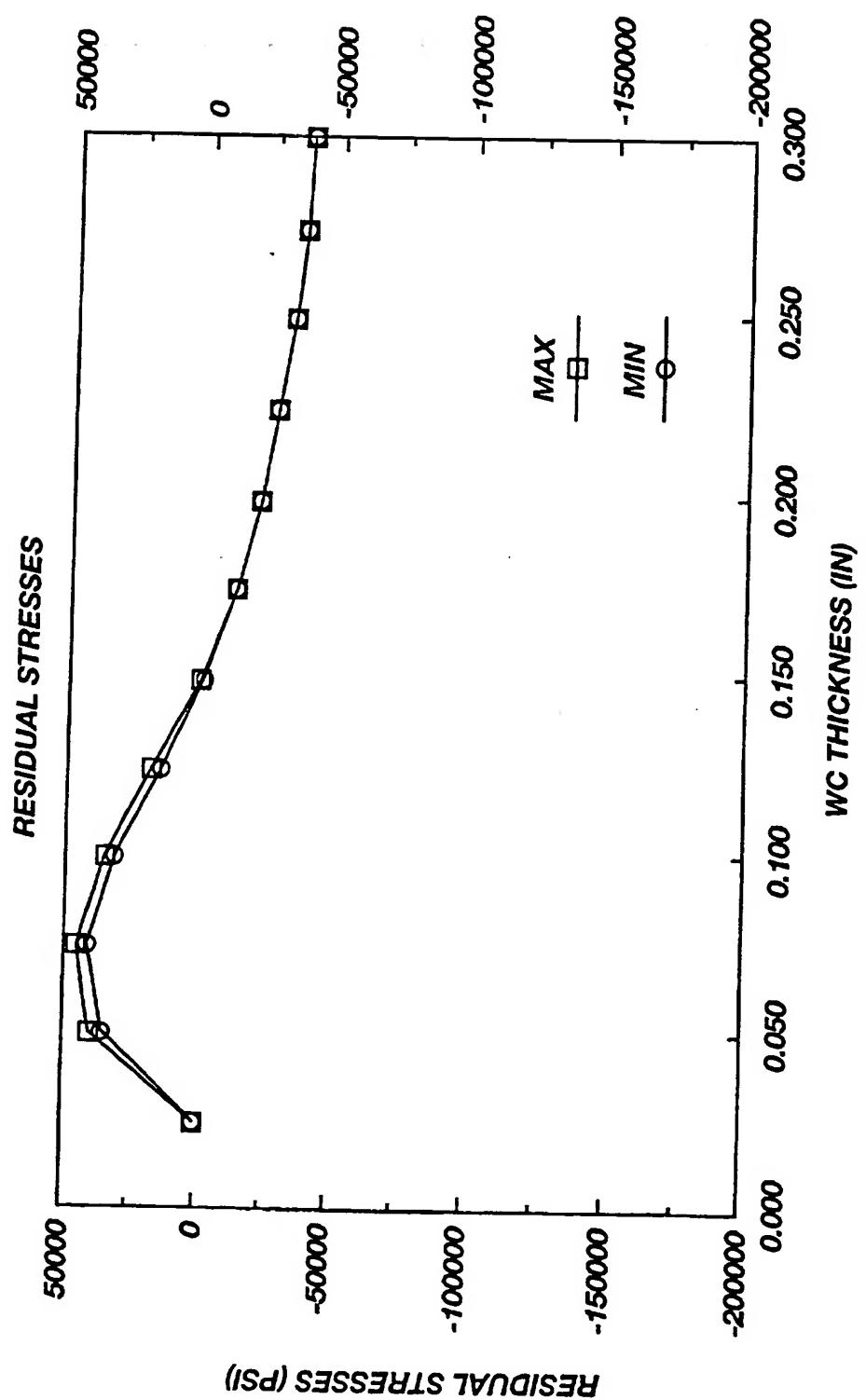


Fig. 8

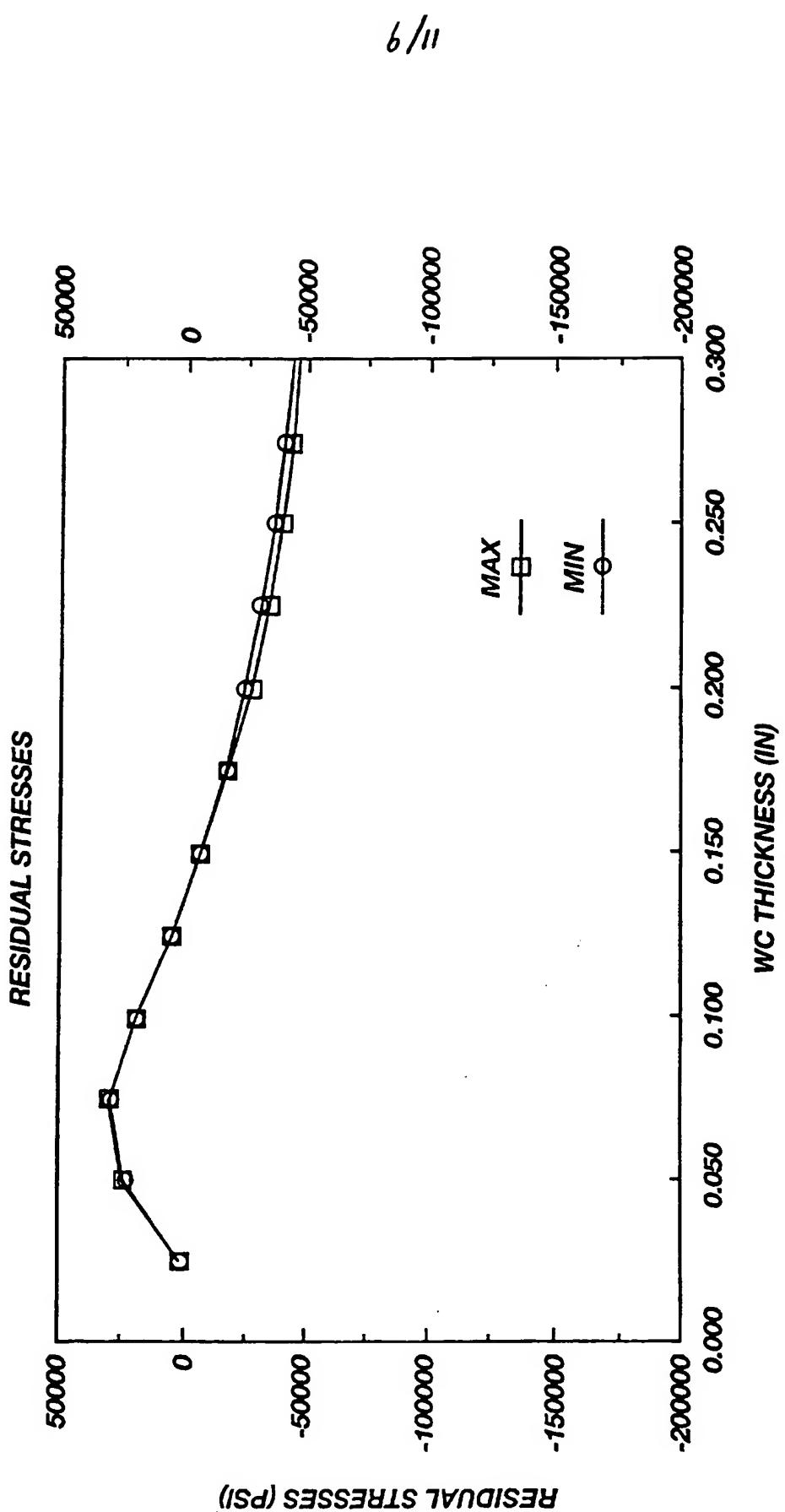
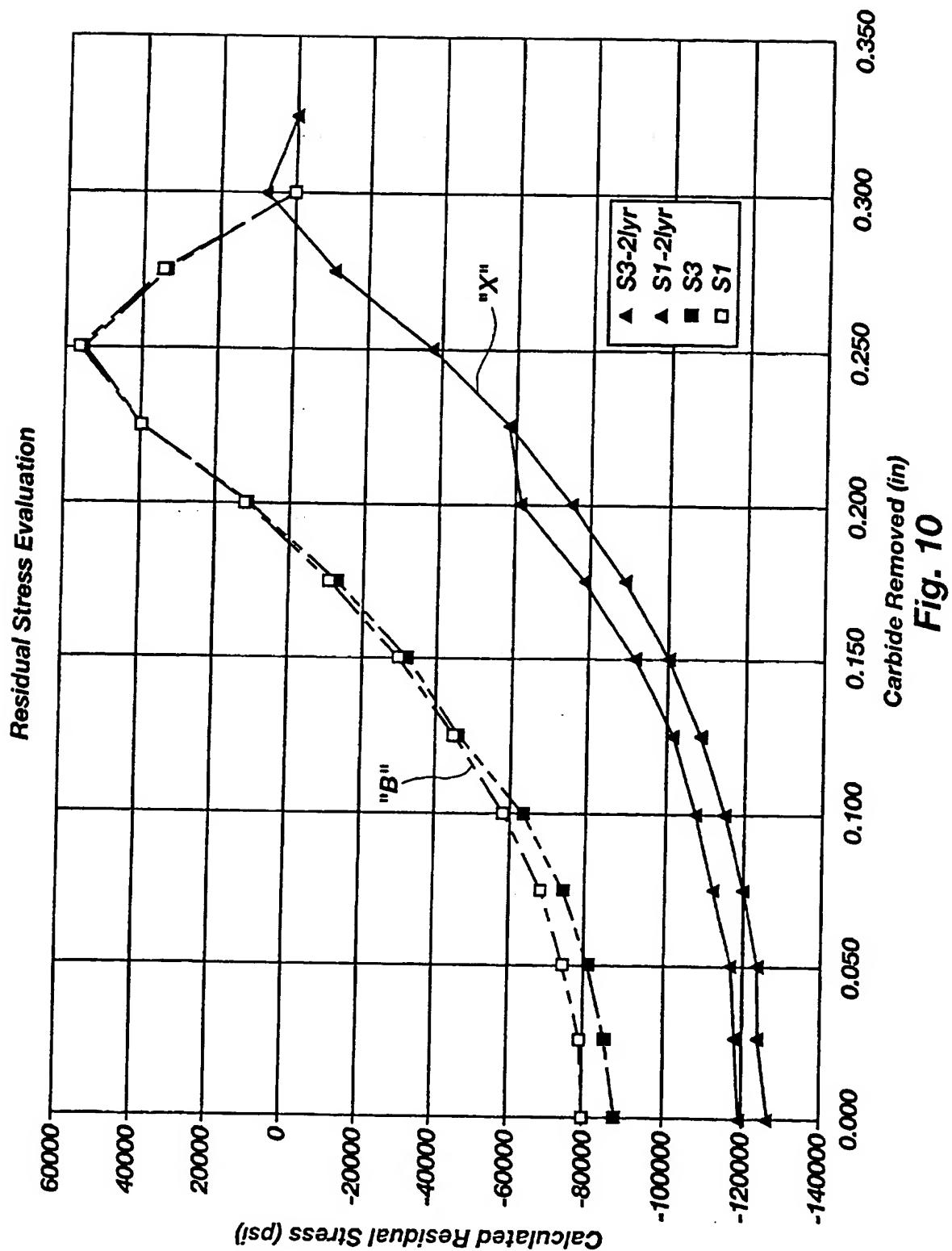


Fig. 9



**Fig. 10**

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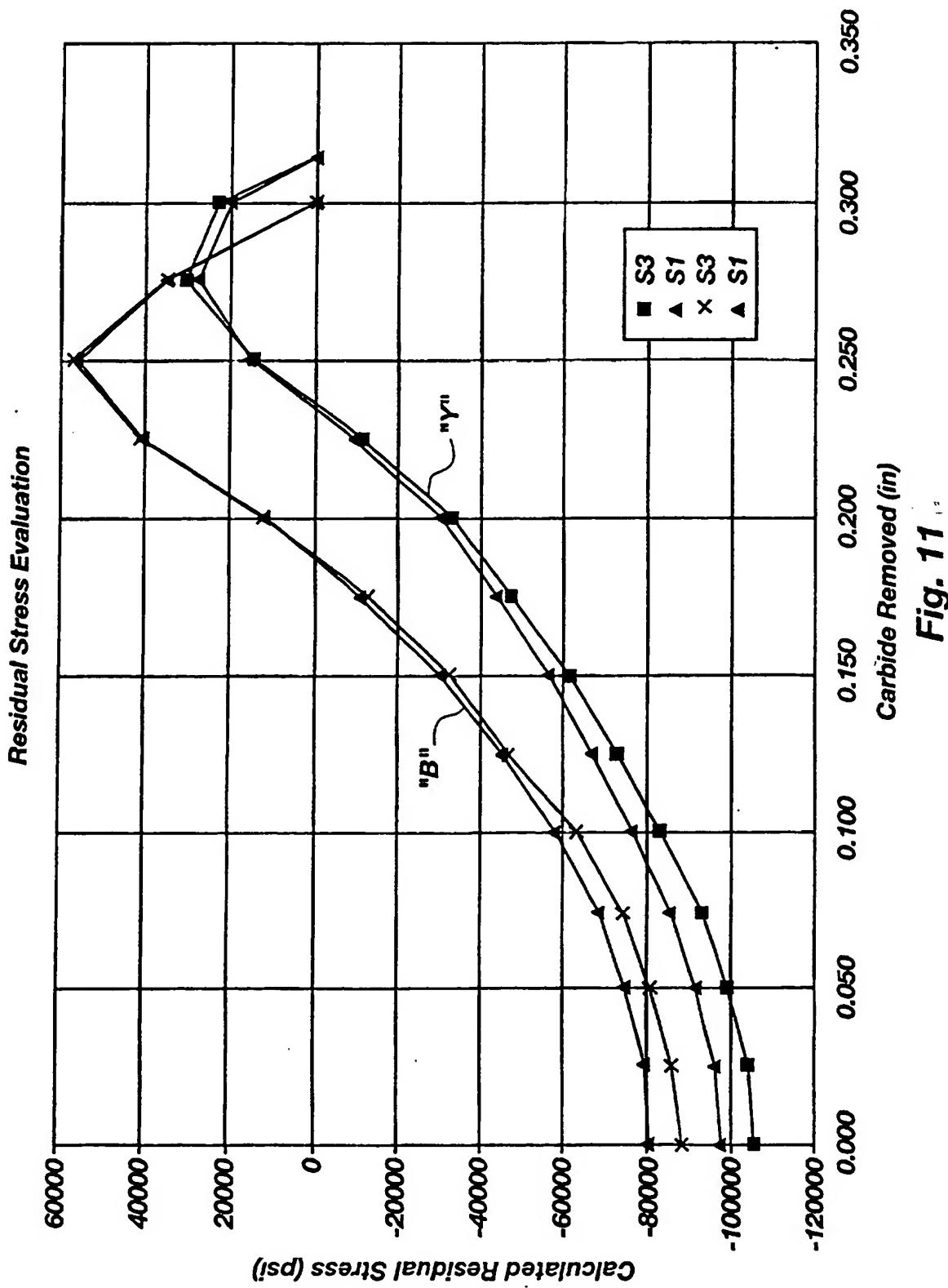


Fig. 11

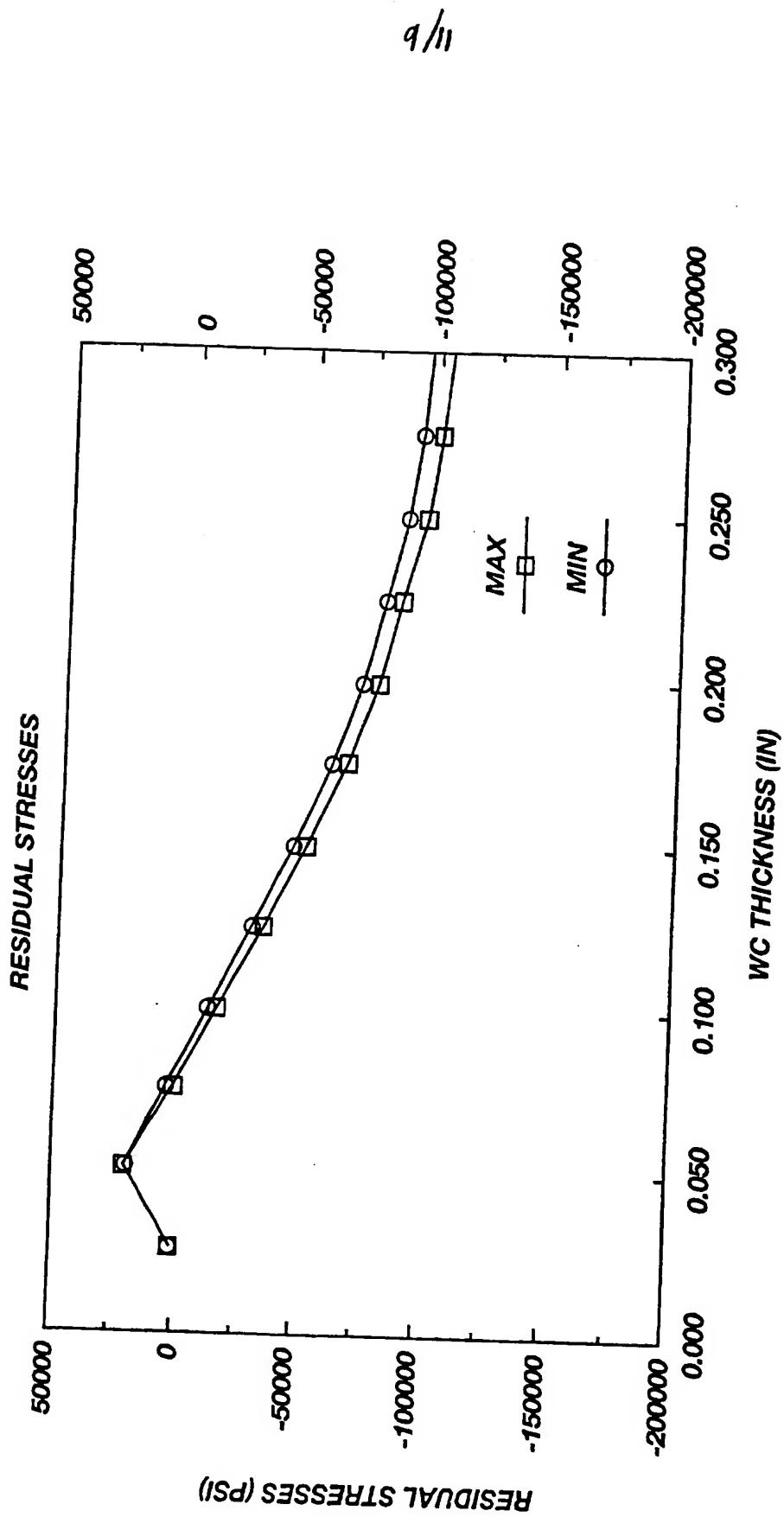


Fig. 12

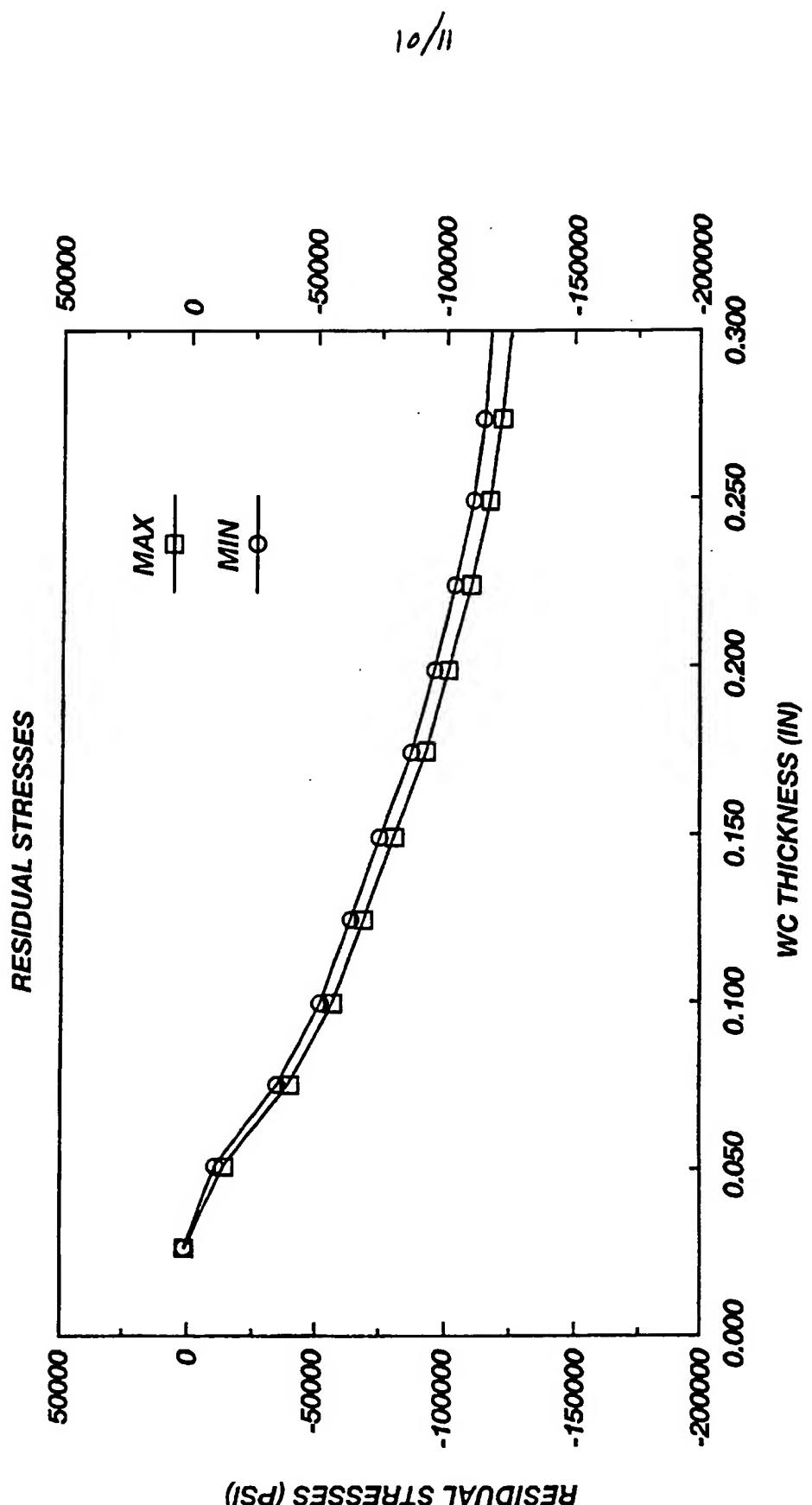
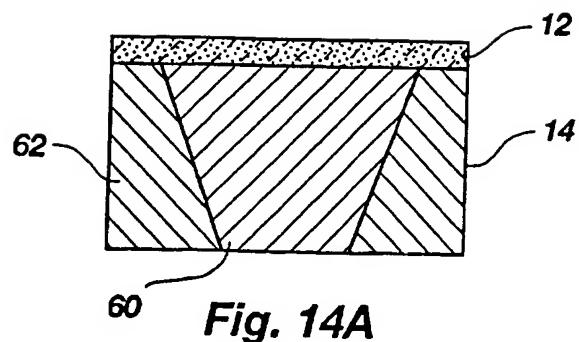
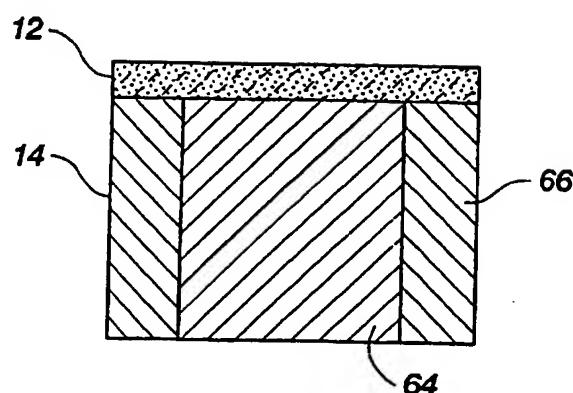


Fig. 13

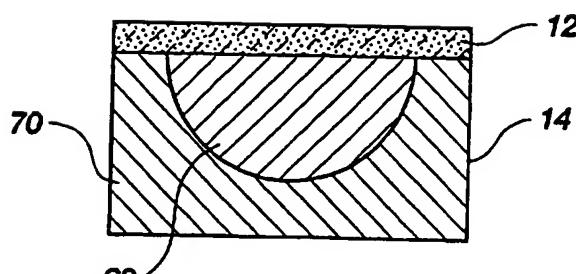
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**Fig. 14A**



**Fig. 14B**



**Fig. 14C**

**POLYCRYSTALLINE DIAMOND CUTTERS HAVING  
MODIFIED RESIDUAL STRESSES**

**BACKGROUND OF THE INVENTION**

5        Field of the Invention: This invention relates to polycrystalline diamond cutters for use in earth boring bits. Specifically, this invention relates to polycrystalline diamond cutters which have modified substrates to selectively modify and alter residual stress in the cutter structure.

10      Statement of the Art: Polycrystalline diamond compact cutters (hereinafter referred to as "PDC" cutters) are well-known and widely used in drill bit technology as the cutting element of certain drill bits used in core drilling, oil and gas drilling, and the like. Polycrystalline diamond compacts generally comprise a polycrystalline diamond (hereinafter "PCD") table formed on a carbide substrate by a high temperature-high pressure (HTHP) sintering process. The PCD and substrate compact may be attached to 15 an additional or larger (i.e., longer) carbide support by, for example, a brazing process. Alternatively, the PCD table may be formed on an elongated carbide substrate in a sintering process to form the PDC with an integral elongated support. The support of the PDC cutter is then brazed or otherwise attached to a drill bit in a manner which exposes the PCD to the surface for cutting.

20      It is known that PDC cutters, by virtue of the materials comprising the PCD table and the support, inherently have residual stresses existing in the compact therebetween, throughout the table and the carbide substrate, and particularly at the interface. That is, the diamond and the carbide have varying coefficients of thermal expansion, elastic moduli and bulk compressibilities such that when the PDC is formed, 25 the diamond and the carbide shrink by different amounts. As a result, the diamond table tends to be in compression while the carbide substrate and/or support tend to be in tension. Fracturing of the PDC can result, often in the interface between the diamond table and the carbide, and/or the cutter may delaminate under the extreme temperatures and forces of drilling.

30      Various solutions have been suggested in the art for modifying the residual stresses in PDC cutters so that cutter failure is avoided. For example, it has been suggested that configuring the diamond table and/or carbide substrate in a particular way may redistribute the stress such that tension is reduced, as disclosed in U.S. Patent

No. 5,351,772 to Smith and U.S. Patent No. 4,255,165 to Dennis. Other cutter configurations which address reduced stresses are disclosed in U.S. Patent No. 5,049,164 to Horton; U.S. Patent No. 5,176,720 to Martell, et al.; U.S. Patent No. 5,304,342 to Hall; and U.S. Patent No. 4,398,952 to Drake (in connection with the formation of roller cutters).

Recent experimental testing has shown that the residual stress state of the diamond table of a PDC cutter can be controlled by novel means not previously disclosed in the literature. That is, results have shown that a wide range of stress states, from high compression through moderate tension, can be imposed on the diamond table 10 by selectively tailoring the carbide substrate. Thus, it would be advantageous in the art to provide a PDC having selectively tailored stress states, and to provide methods for producing such PDC's.

#### BRIEF SUMMARY OF THE INVENTION

In accordance with the present invention, a polycrystalline diamond compact cutter having a tailored carbide substrate which favorably alters the compressive stresses in the diamond table and residual tensile stresses within the carbide substrate is provided to produce a PDC with improved stress characteristics. Modification of the substrate to tailor the stress characteristics in the diamond table and substrate may be 20 accomplished by selectively thinning the carbide substrate subsequent to HTHP processing, by selectively varying the material constituents of the substrate, by subjecting the PDC to an annealing process during sintering, by subjecting the formed PDC to a post-process stress relief anneal, or a combination of those means.

The PDC cutters of the present invention are comprised of a polycrystalline diamond table, a carbide substrate on which the polycrystalline diamond table is formed (e.g., sintered) and, optionally, a carbide support of typically greater thickness than either the diamond table or the substrate to which the substrate is connected (e.g., brazed). However, it has been discovered that a wide range of stress states, from high compression through moderate tension, can be imposed in the diamond table by 25 selectively tailoring the carbide substrate thickness. The carbide substrate may be formed with a selected thickness by the provision of sufficient carbide material during the HTHP sintering process to produce the desired thickness. In addition, or 30

alternatively, once the PDC is formed, the substrate may be selectively thinned by subjecting it to a grinding process or machining or by electro-discharge machining processes.

It has been shown through experimental and numerical residual stress analyses  
5 that the magnitude of stress existing in the diamond table is related to the thickness of the support. Thus, within a suitable range, the carbide substrate of the cutter may be thinned to achieve a desired magnitude of stress in the diamond table appropriate to a particular use. The achievement of an appropriate or desired degree of thinness in the carbide support, and therefore the desired magnitude of stress, may be determined by  
10 residual stress analyses.

The substrate of the PDC cutter may typically be made of cobalt-cemented tungsten carbide (WC), or other suitable cemented carbide material, such as tantalum carbide, titanium carbide, or the like. The cementing material, or binder, used in the cemented carbide substrate may be cobalt, nickel, iron, alloys formed from  
15 combinations of those metals, or alloys of those metals in combination with other materials or elements. Experimental testing has shown that introduction of a selective gradation of materials in the substrate will produce suitable stress states in the carbide substrate and diamond table. For example, the use of varying qualities of grades or percentages of cobalt-cemented (hereinafter "Co-cemented") carbides in the substrate  
20 produces very suitable states of compression in the diamond table and reduced residual tensile stress in the carbide substrate and provides increased strength in the cutter.

It has also been shown that a PDC cutter with suitably modified stress states in the diamond table and substrate may be formed by selectively manipulating the qualities of grades or percentages of binder content, carbide grain size or mixtures of  
25 binder or carbide alloys in the substrate. Thus, the specific properties of the cutter may be achieved through selectively dictating the metallurgical content of the substrate. Further, subjecting the PDC of the present invention to an annealing step during the sintering process increases the hardness of the diamond table. Subjecting the formed (sintered) PDC cutter to a post-process stress relief anneal procedure provides a further  
30 means for selectively tailoring the stresses in the PDC cutter and improves significantly the hardness of the diamond table. Additionally, tailoring the thickness of the backing

and/or subjecting the substrate to the disclosed annealing processes also provides selected suitable stress states in the diamond table and support.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

5 In the drawings, which illustrate what is currently considered to be the best mode for carrying out the invention,

FIG. 1 is a graph representing the post-HTHP relationship between thickness of the carbide substrate and stress states existing in the surface of the diamond table;

10 FIG. 2 is a view in cross section of a PDC cutter of the present invention having a selectively thinned carbide substrate containing 13% cobalt;

FIG. 3 is a graph illustrating residual stress analyses of a cutter comprised of a 13% cobalt-containing substrate integrally formed with the carbide support in comparison with the residual stress analyses of a cutter as shown in FIG. 2 which is attached to a 5 mm support;

15 FIG. 4 is a graph illustrating residual stress analyses of a cutter comprised of a 13% cobalt-containing substrate integrally formed with the carbide support in comparison with the residual stress analyses of a cutter of the type shown in FIG. 2 which is attached to a 3 mm support;

20 FIG. 5 is a view in cross section of a second embodiment of a PDC cutter of the present invention having a substrate of varying materials content;

FIG. 6 is a view in cross section of a third embodiment of a PDC cutter of the present invention having a substrate comprised of three layers of disparate materials content;

25 FIG. 7 is a graph illustrating residual stress analyses conducted on a PDC cutter having a substrate with a 13% cobalt content integrally formed to a carbide support where the cutter was made in a belt press;

FIG. 8 is a graph illustrating residual stress analyses conducted on a PDC cutter having a substrate with a 16% cobalt content where the cutter was made in a belt press;

30 FIG. 9 is a graph illustrating residual stress analyses conducted on a PDC cutter as shown in FIG. 5 made in a belt press;

FIG. 10 is a graph illustrating the residual stress analyses of a cutter comprised of a substrate containing 13% cobalt integrally formed to a carbide support compared to the residual analyses of the cutter shown in FIG. 5 made in a cubic press;

5 FIG. 11 is a graph illustrating the residual stress analyses of a cutter comprised of a substrate containing 13% cobalt integrally formed to a carbide support compared to the residual analyses of the cutter shown in FIG. 6 made in a cubic press;

FIG. 12 is a graph illustrating the residual stress analyses of a cutter comprised of a substrate containing 13% cobalt integrally formed to a carbide support which was produced with a post process annealing step;

10 FIG. 13 is a graph illustrating the residual stress analyses of the cutter embodiment shown in FIG. 5 produced with a post process annealing step; and

FIGS. 14A-C are views in cross section of alternative configurations for forming a substrate with varying materials content.

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## DETAILED DESCRIPTION OF THE INVENTION

It is known that the difference in coefficients of thermal expansion between diamond and carbide materials results in the bulk of the diamond table of a PDC being in compression and the bulk of the carbide substrate being in tension following the HTHP sintering process used to form a PDC cutter. The respective existences of compression and tension states in the diamond table and substrate components of a PDC have been demonstrated through residual stress analyses. Residual stress analyses have also demonstrated, however, an ability to tailor the residual stress states which exist in the diamond table and substrate of the PDC cutter by reducing the thickness of the carbide substrate, or varying the properties of the carbide substrate.

25

The correlation is illustrated by FIG. 1 where residual stress states at the interface between the diamond table and the substrate are represented on the y-axis and relative thicknesses of the carbide substrate are represented on the x-axis. Testing with a tungsten carbide substrate sintered to a diamond table indicates that at a carbide substrate thickness of about 10 mm, the residual stress in the diamond table tends to be in the range of about -100 ksi to -80 ksi. As the thickness of the substrate is decreased to about 6 mm, the residual stress in the diamond table approaches zero ksi, and further reduction of the thickness of the substrate results in residual tensile stresses before

further reductions in thickness reduce the diamond to a zero stress state. Thus, it can be seen that a selected stress state in the cutter may be achieved by selectively thinning the substrate to the thickness required to achieve that desired residual stress state.

Generally, it is thought to be desirable to reduce the residual tensile stresses in the

5 carbide substrate to a minimum level. However, it may be desirable to produce a cutter with an otherwise elevated residual tensile stress state in the substrate in order to meet the particular needs of an application or operation. For example, substrate thicknesses ranging from about 17.0 mm to about 4.0 mm for a cutter having a three-quarter inch diameter may be particularly suitable in terms of the stresses achieved in the substrate.

10 The suitable thickness of the substrate will depend on the diameter of the cutter and the intended drilling environment.

Accordingly, in a first embodiment of the invention, represented in FIG. 2, a PDC cutter 10 is formed with a polycrystalline diamond table 12 and a carbide substrate 14 connected to the diamond table 12. The diamond table 12 may be formed on the

15 substrate 14 in a conventional manner, such as by an HTHP sintering process. The carbide substrate 14 may then be connected to an additional carbide support 16, also called a cylinder, by such methods as a braze joint 18. The diamond table 12 may be of conventional thickness 20, approximately 1.0 mm to about 4 mm (about 0.04 inches to about 0.157 inches). The carbide support 16 may generally be formed of any suitable

20 carbide material, such as tungsten carbide, tantalum carbide or titanium carbide with various binding metals including cobalt, nickel, iron, metal alloys, or mixtures thereof.

The thickness 22 of the carbide support 16 may range, depending on the cutter diameter, from about 5 mm to about 16 mm.

The substrate 14 of the illustrated embodiment may be comprised of any

25 conventional cemented carbide, such as tungsten carbide, tantalum carbide or titanium carbide. Additionally, the substrate may contain additional material, such as cobalt, nickel, iron or other suitable material. The substrate 14 may be selectively thinned subsequent to sintering from its original thickness to achieve a desired residual stress state by any of a number of methods. For example, the thickness 24 of the substrate 14

30 may be selected initially, in the formation of the cutter 10, to provide a final, post-sintering substrate 14 of the desired thickness 24. Alternatively, the substrate 14 may be formed by conventional methods to a conventional thickness, and the substrate 14

may thereafter be selectively thinned along the planar surface 26 to which the support 16 is thereafter joined. The substrate 14 may be thinned by grinding the planar surface 26 using grinding methods known in the art, or the substrate 14 may be thinned by employing an electro-discharge or other machining process. The substrate 14 is thinned

5 to remove a sufficient amount of material from the substrate 14 to achieve the desired residual stress levels. The substrate 14 and diamond table 12 assembly may then be attached to the additional carbide support 16 by brazing or another suitable technique.

Alternatively, the diamond table 12 may be formed on the substrate 14 by conventional methods to provide a conventional thickness, and the diamond table 12

10 and substrate 14 assembly may then be joined to the additional carbide support 16. Thereafter, the total thickness of the substrate 14 plus support 16 may be modified by grinding, machining (e.g., sawing) or by electro-discharge machining processes.

FIGS. 3 and 4 illustrate that an advantageous effect on modifying residual stress is gained by thinning the substrate 14 prior to attaching the substrate 14 to the carbide

15 support 16 as compared to the residual stresses experienced in a substrate that is integrally formed with the support 16. FIG. 3, for example, compares a cutter "A" comprised of a 13% cobalt-containing substrate of selected thickness (e.g., 3 mm), which was thinned to that selected thickness prior to attachment, such as by brazing, to a 5 mm carbide support, with a cutter "B" comprised of a 13% cobalt-containing

20 substrate integrally formed with a carbide support and subsequently thinned to a selected thickness comparable to cutter "A" (e.g., 8 mm). FIG. 3 illustrates that as the cutter is reduced in thickness by the removal of carbide from the support, a beneficial change in residual stress is experienced until a maximum effect is achieved at about a 0.25 inch removal of carbide. Cutter "A" shows an improved residual stress state at

25 that point in comparison to cutter "B."

FIG. 4 similarly illustrates a cutter "C" comprised of a 13% cobalt-containing substrate of selected thickness (e.g., 5 mm), which was thinned to that selected thickness prior to attachment to a 3 mm carbide support, compared with a cutter "D" comprised of a 13% cobalt-containing substrate integrally formed with a carbide

30 support and thinned to a selected thickness comparable to cutter "C" (e.g., 8 mm). FIG. 4 illustrates that as the cutter is reduced in thickness by the removal of carbide from the

substrate, a beneficial change in residual stress is experienced with cutter "C" demonstrating an increased benefit in modification of the residual stress state.

FIG. 7 also demonstrates the advantageous effect on residual stress in the substrate of a PDC cutter resulting from a reduction of the substrate thickness. As 5 illustrated in FIG. 7, residual stress analyses were performed on a conventional PDC comprising a diamond table having a thickness of between about 0.028 inches and 0.030 inches and a carbide substrate composed of 13% cobalt, which was thinned from about 0.300 inches to about 0.025 inches. The graph of FIG. 7 illustrates that as the thickness of the carbide support is decreased, the residual tensile stress in the substrate 10 of the cutter is advantageously modified.

The residual stresses in the diamond table of a PDC cutter may also be modified and tailored by selectively modifying the materials content of the substrate of the PDC. Specifically, a PDC 30 as illustrated FIG. 5 may be formed with a diamond table 32 connected to a substrate 34 having a varying or graded materials content. The substrate 15 34 may, in turn, be attached to a carbide support 36. The formation of the substrate 34 of this embodiment may be accomplished by joining together two or more disparate carbide discs 38, 40 in the HTHP sintering process to form the PDC. The carbide discs 38, 40 may vary from each other in binder content, carbide grain size, or carbide alloy content. The discs 38, 40 may be selected and arranged, therefore, to produce a 20 gradient of materials content in the substrate which modifies and provides the desired compressive or reduced residual tensile stress states in the diamond table 32.

Alternatively, as shown in FIGS. 14A, 14B and 14C, a substrate 14 of varying materials content can be produced by conjoining in a sintering or other suitable process substructures of the substrate 14, each of which contains a different material 25 composition or make-up. For example, FIG. 14A illustrates a substrate of varying materials content comprised of a conically-shaped inner element 60 surrounded by an outer tubular body 62 sized to receive the conically-shaped inner element 60 prior to sintering. The conically-shaped inner element 60 may, for example, contain 13% cobalt while the outer tubular body 62 contains 20% cobalt. By further example, FIG. 14B 30 illustrates a substrate 14 formed of an inner cylinder 64 of, for example, 16% cobalt surrounded by an outer tubular body 66 of 20% cobalt-containing carbide. FIG. 14C further illustrates another alternatively formed substrate 14 comprised of an inversely

dome-shaped member 68 having, for example, a cobalt content of 13% which is received within an outer member 70 of 20% cobalt-containing carbide formed with a cup-shaped depression sized to receive the dome-shaped member 68 therein prior to sintering. Any number of other shapes of elements may be combined to produce a  
5 substrate of varying materials content in accordance with the present invention.

By way of example only, and again with reference to FIG. 5, a PDC 30 may be formed by joining together in the HTHP sintering process a first carbide disc 38 having a 13% cobalt content and a second carbide disc 40 having a 16% cobalt content. The two discs 38, 40 are placed in a cylinder for processing along with diamond grains in  
10 the conventional manner for forming a PDC cutter. The diamond and carbide discs are then subjected to a sintering cycle with an in-process annealing procedure which comprises the steps of 1) ramping up to a pressure of 60 K bars and temperature of 1450° C over a period of one minute; 2) processing the sintering cycle for eight minutes; 3) ramping down the temperature approximately 100°C while maintaining a  
15 constant pressure to get below the solidus of the carbide material; 4) maintaining a dwell of four to six minutes to anneal the sintered mass, and 5) finally ramping down the cycle over approximately a two-minute period. A compact formed by the described process produces a PDC cutter having favorably altered residual stresses patterns. The residual stress in the PDC cutter thus formed is modified from that of a cutter with a  
20 single 13% or 16% cobalt-cemented carbide material. As illustrated in FIG. 6, the cutter 50 may be comprised of a substrate 14 having three or more layers of similar or disparate materials. FIG. 6 illustrates a cutter 50 having a first layer 52 containing 13% cobalt, a second layer 54 containing 16% cobalt and a third layer 56 containing 20% cobalt. The thickness of the layers may be varied or may be the same.  
25

The advantageous modification of residual stress in the substrate resulting from a selected modification of the material of the substrate is demonstrated in FIGS. 7, 8 and 9, which illustrate residual stress analyses performed on various cutter embodiments, each of which was formed using a conventional belt press method. FIG. 7, as previously described, illustrates residual stress analyses performed on a  
30 conventional PDC cutter comprising a diamond table having a thickness of between about 0.028 inches and 0.030 inches and a carbide substrate composed of 13% cobalt. FIG. 8 illustrates residual stress tests that were performed on a PDC cutter as shown in

FIG. 2 having a single layer substrate composed of 16% cobalt where the thickness of the diamond table 12 was from about 0.028 inches to about 0.030 inches and the substrate 14 varied in thickness from about 0.300 inches to about 0.025 inches. FIG. 9 illustrates residual stress analyses performed on a PDC cutter as shown in FIG. 5 where the thickness of the diamond table 32 was between 0.028 inches and 0.030 inches, and the combined thickness of the first carbide disc 38 (13% cobalt) and the second disc 40 (16% cobalt) ranged from between about 0.028 inches and 0.030 inches.

FIG. 7 illustrates that a maximum compressive stress of about 75,000 psi is achieved at a carbide substrate thickness of about 0.030 inches, but reducing the carbide thickness achieves a residual tensile stress of about 10,000 psi for a full spread of 85,000 psi. FIG. 8 illustrates that a maximum compressive stress reaches about 40,000 psi and, upon reduction of the carbide thickness, residual tensile stress is modified to 40,000 psi with an overall change of 85,000 psi. FIG. 9 illustrates that the maximum residual compressive stress in a bi-layered cutter (FIG. 5) is about 45,000 psi, but a residual tensile stress of about 25,000 psi is achieved through reduction of the carbide thickness, resulting in an overall change of 70,000 psi, or 18%.

FIGS. 3, 10 and 11 further demonstrate the advantageous change in residual stress in the substrate on cutters produced using a cubic press. Thus, FIG. 3 illustrates residual stress analyses on a cutter as shown in FIG. 2, denoted "A", in comparison with a standard cutter where the substrate, containing 13% cobalt, is integrally formed with the support, denoted "B." FIG. 10 illustrates residual stress analyses on a cutter, denoted "X", as shown in FIG. 5 in comparison with the standard, integrally formed cutter, denoted "B." FIG. 11 illustrates residual stress analyses on a cutter as shown in FIG. 6, denoted "Y", in comparison with the standard integrally formed cutter "B". In FIG. 3, it is shown that the maximum residual compressive stress in cutter "B" is 85,000 psi, and reducing the carbide thickness achieves a peak tensile stress of 58,000 psi, with an overall change of 143,000 psi. FIG. 10 demonstrates that the maximum residual compressive stress in cutter "X" is about 128,000 psi, but with reduction of the carbide, the maximum residual tensile stress reaches about 8,000 psi, with an overall change of 136,000 psi. The direction of the modification of the residual stress is substantially different than that experienced in cutter "B." FIG. 11 illustrates that the maximum residual compressive stress for cutter "Y" is 112,000 psi and reduction of the

carbide support thickness achieves a maximum residual tensile stress of 30,000 psi with an overall change of 142,000 psi. Formation of the cutter in a belt press results in a greater change in residual stresses for given substrate thicknesses as compared to cutters made in a cubic press. Further, while the maximum residual compressive stress is

5 much higher for cutters made in a cubic press, the maximum residual tensile stresses are much lower in layered or graded substrates as compared with integrally formed cutters. These test results indicate that residual stresses can be tailored by thinning the carbide, by varying the content of the substrate and by selecting the method of manufacture of the cutter.

10 Notably, Knoop hardness testing conducted on the PDC's illustrated in FIGS. 2 and 5 indicated a hardness of 3365 (KHN) in the diamond table of the conventional PDC (13% cobalt content) and a hardness of 3541 (KHN) in the diamond table of the embodiment illustrated in FIG. 5, suggesting that the substrate content and the in-process annealing procedure impart beneficial characteristics of diamond table hardness

15 as well as modified residual stresses in the diamond table.

A post-process stress thermal treatment cycle is also beneficial in reducing the residual stresses experienced in the diamond table. The post-process stress relief anneal cycle comprises the steps of subjecting a sintered compact (i.e., the diamond table and substrate) to a temperature of between about 650°C and 700°C for a period of one hour

20 at less than 200  $\mu$  of vacuum pressure. Notably, the heat up and cool down cycles of the process are controlled over a three-hour period to promote even and gradual cooling, thereby reducing the residual stress forces in the cutter.

Comparative Knoop hardness testing performed on a conventional PDC, as described above with a 13% cobalt content in the carbide substrate, and a PDC as

25 illustrated in FIG. 5, both of which were subjected to a post-process stress relief anneal cycle, demonstrates that both the conventional PDC and the PDC of the present invention experience unexpected increases in hardness levels as compared to a conventional PDC and a PDC of the present invention which are not subjected to a post-process stress relief anneal cycle. The effect of a post-process stress relief anneal

30 cycle on a third kind of PDC having a catalyzed substrate was also observed. These results are illustrated in Table I.

TABLE I

	Without Post-Process Anneal	With Post-Process Anneal
Conventional PDC (13% Co Substrate)	3365 (KHN)	3760 (KHN)
Varied Substrate PDC (13% Co/16% Co)	3541 (KHN)	3753 (KHN)
Catalyzed Substrate (layer of Co between carbide and diamond)	3283 (KHN)	3599 (KHN)

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Further evidence of the difference effected on residual stress by use of a post annealing process can be observed in a comparison of FIG. 7 with FIG. 12. FIG. 7 illustrates residual stress analyses on a cutter having a 13% cobalt-containing substrate which was produced with no post-process annealing while FIG. 12 illustrates the same embodiment produced with a post-process annealing procedure. The residual compressive stress is a maximum of about 80,000 psi in the cutter shown in FIG. 3, but is approximately 25% higher, or at about 100,000 psi in the cutter shown in FIG. 12. Additional support can be seen in a comparison of the residual stress analyses shown in FIG. 9 of the cutter embodiment shown in FIG. 5, which was produced without a post-process annealing step and the residual stress analyses shown in FIG. 13 of the cutter embodiment shown in FIG. 5, which was produced with a post annealing process step. The maximum compressive stress is under about 50,000 psi for the cutter tested in FIG. 9 while the maximum compressive stress is over about 120,000 psi for the annealed counterpart shown in FIG. 13.

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The present invention is directed to providing polycrystalline diamond compact cutters having selectively modified residual stress states in the diamond table and substrate or support thereof. Through the means of selective thinning of the substrate and/or support, through the means of selectively modifying the materials content of the substrate, through the means of subjecting the PDC to in-process annealing procedures, and through the means of subjecting a sintered PDC to a post-process stress relief annealing procedure, or combinations of all these means, desired residual stresses and

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compressive forces in a PDC cutter may be achieved. The concept may be adapted to virtually any type or configuration of PDC cutter and may be adapted for any type of drilling or coring operation. The structure of the PDC cutters of the invention may be modified to meet the demands of the particular application. Hence, reference herein to  
5 specific details of the illustrated embodiments is by way of example and not by way of limitation. It will be apparent to those skilled in the art that many additions, deletions and modifications to the illustrated embodiments of the invention may be made without departing from the spirit and scope of the invention as defined by the following claims.

CLAIMS

What is claimed is:

1. A polycrystalline diamond compact cutter having selectively modified residual stress states comprising:
  - 5 a polycrystalline diamond table;
  - a carbide substrate secured to said polycrystalline diamond table, said carbide substrate having a thickness of selected dimension and being comprised of carbide and binder constituents selected to provide a desired state of compression in said diamond table and a desired residual stress state in said substrate; and
  - 10 a support to which said carbide substrate is attached.
2. The polycrystalline diamond compact cutter of claim 1 where said substrate thickness ranges from about 0.025 inches to about 0.30 inches.
- 15 3. The polycrystalline diamond compact cutter of claim 2 wherein said substrate is formed from carbides selected from the group comprising tungsten carbide, tantalum carbide or titanium carbide.
4. The polycrystalline diamond compact cutter of claim 3 wherein said 20 binder constituents are selected from the group consisting of cobalt, nickel, iron, and alloys formed from combinations of those metals.
5. The polycrystalline diamond compact cutter of claim 2 wherein a thickness of said support ranges from about 5 mm to about 16 mm.
- 25 6. The polycrystalline diamond compact cutter of claim 1 wherein said carbide substrate is formed from at least two carbide disks each having dissimilar materials content from each other.
- 30 7. The polycrystalline diamond compact cutter of claim 6 wherein said substrate is comprised of two disks formed together, a first disk comprised of 13%

cobalt-containing carbide and a second disk comprised of 16% cobalt-containing carbide.

8. The polycrystalline diamond compact cutter of claim 7 wherein said first  
5 disk comprised of 13% cobalt-containing carbide is located adjacent said table.

9. The polycrystalline diamond compact cutter of claim 6 wherein said substrate is comprised of three disks formed together, a first disk comprised of 13% cobalt-containing carbide, a second disk comprised of 16% cobalt-containing carbide  
10 and a third disk comprised of 20% cobalt-containing carbide.

10. The polycrystalline diamond compact cutter of claim 9 wherein said third disk comprised of 20% cobalt-containing carbide is positioned apart from said table.

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11. The polycrystalline diamond compact cutter of claim 1 wherein said substrate is formed from an inner, non-planar carbide member positioned within and bonded to an outer carbide member.

20 12. The polycrystalline diamond compact cutter of claim 11 wherein said inner carbide member and said outer carbide member are comprised of dissimilar materials content.

25 13. The polycrystalline diamond compact cutter of claim 11 wherein said inner carbide member is conically shaped and said outer carbide member is sized to receive said inner carbide member therewithin.

30 14. The polycrystalline diamond compact cutter of claim 11 wherein said inner carbide member is cylindrically shaped and said outer carbide member is formed as a sleeve sized to encircle said inner cylindrically shaped carbide member.

15. The polycrystalline diamond compact cutter of claim 11 wherein said inner carbide member is hemispherically shaped and said outer carbide member is formed with a depression sized to receive said inner carbide member therewithin.

5        16. A polycrystalline diamond compact cutter having selectively modified residual stress states comprising:  
a polycrystalline diamond table;  
a carbide substrate to which said polycrystalline diamond table is bonded, said carbide substrate being selectively formed with at least one additional material therein  
10      selectively arranged to achieve a desired state of compression in the diamond table and a desired reduced residual stress state in said substrate; and  
a carbide support to which said carbide substrate is attached.

15      17. The polycrystalline diamond compact cutter of claim 16 wherein said at least one additional material is selected from the group consisting of cobalt, nickel and iron.

20      18. The polycrystalline diamond compact cutter of claim 17 wherein said carbide substrate is formed from at least two carbide discs joined together in a sintering process, said at least two carbide discs containing disparate amounts of said at least one additional material.

25      19. The polycrystalline diamond compact cutter of claim 18 wherein said carbide substrate is formed from a first carbide disc containing thirteen percent cobalt and a second carbide disc containing sixteen percent cobalt, said first disc being positioned adjacent to said polycrystalline diamond table.

30      20. The polycrystalline diamond compact cutter of claim 19 further comprising a third disc of carbide material containing twenty percent cobalt.

21. A method of forming a polycrystalline diamond compact cutter having selectively modified residual stress states comprising:

placing in a processing container an amount of diamond grains and carbide material to form a polycrystalline diamond table and carbide substrate, respectively; subjecting said diamond grains and carbide material to a high pressure, high temperature sintering process comprising:

5 ramping up temperature and pressure over a one minute period; subjecting the diamond grains and carbide material to sustained sintering at a pressure level of at least 60 Kb and at a temperature of about 1450° C for a period of approximately eight minutes;

ramping down said temperature about one hundred degrees centigrade to drop

10 below solidus of the carbide material;

maintaining a dwell period of about four minutes to about six minutes to anneal said diamond grains and carbide material into a sintered compact; and

ramping down said pressure and temperature over a two-minute period; and

bonding said sintered compact to a carbide support.

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22. The method according to claim 21 wherein said carbide material comprises carbide and additional materials selectively arranged to achieve a desired state of compression in the diamond table of said sintered compact and a reduced residual tensile stress state in said carbide substrate.

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23. The method according to claim 22 further comprising selectively thinning said carbide support following said bonding of said sintered compact to said carbide support to achieve a desired state of compression in the diamond table and a desired modified residual stress state in said substrate carbide.

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24. The method according to claim 22 further comprising selectively thinning said carbide substrate of said sintered compact prior to bonding said sintered compact to said carbide support to achieve a desired state of compression in the diamond table and a desired modified residual stress state in said substrate carbide.

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25. The method according to claim 24 further comprising subjecting said sintered compact to a post-process stress thermal treatment procedure prior to said bonding of said sintered compact to said carbide support, said procedure comprising; placing said sintered compact in a reaction vessel;

5 gradually reducing pressure and temperature in the vessel;  
maintaining said sintered compact at about 200  $\mu$  of vacuum for about one hour;  
and

gradually reducing said pressure and temperature in the vessel.

10 26. The method according to claim 25 further comprising subjecting said sintered compact to a post-process anneal prior to said bonding to said carbide support.

27. The method according to claim 21 further comprising subjecting said sintered compact to a post-process stress thermal treatment procedure prior to said  
15 bonding of said sintered compact to said carbide support, said procedure comprising;

placing said sintered compact in a reaction vessel;  
gradually reducing pressure and temperature in the vessel;  
maintaining said sintered compact at about 200  $\mu$  of vacuum for about one hour;

and

20 gradually reducing said pressure and temperature in the vessel.

28. The method according to claim 27 further comprising subjecting said sintered compact to a post-process anneal prior to said bonding to said carbide support.

25 29. The method according to claim 22 further comprising subjecting said sintered compact to a post-process stress thermal treatment procedure prior to said bonding of said sintered compact to said carbide support, said procedure comprising;

placing said sintered compact in a reaction vessel;  
gradually reducing pressure and temperature in the vessel;

30 maintaining said sintered compact at about 200  $\mu$  of vacuum for about one hour;  
and

gradually reducing said pressure and temperature in the vessel.

30. The method according to claim 29 further comprising subjecting said sintered compact to a post-process anneal prior to said bonding to said carbide support.



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Application No: GB 9930844.7  
Claims searched: 1-30

Examiner: Ian Blackmore  
Date of search: 10 May 2000

**Patents Act 1977**  
**Search Report under Section 17**

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): E1F FFD, FFU, FGB, FGC

Int Cl (Ed.7): E21B 10/16, 10/46, 10/56

Other: Online: EPODOC, JAPIO, WPI

**Documents considered to be relevant:**

Category	Identity of document and relevant passage	Relevant to claims
X	GB 2307931 A (BAKER HUGHES INCORPORATED) see figure 1 and page 4, lines 1-4	1
X	GB 2258260 A (CAMCO DRILLING GROUP) see whole document	1

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.